Real-Time Optical Receiver

NASA Technology Transfer Program Webinar

April 2023

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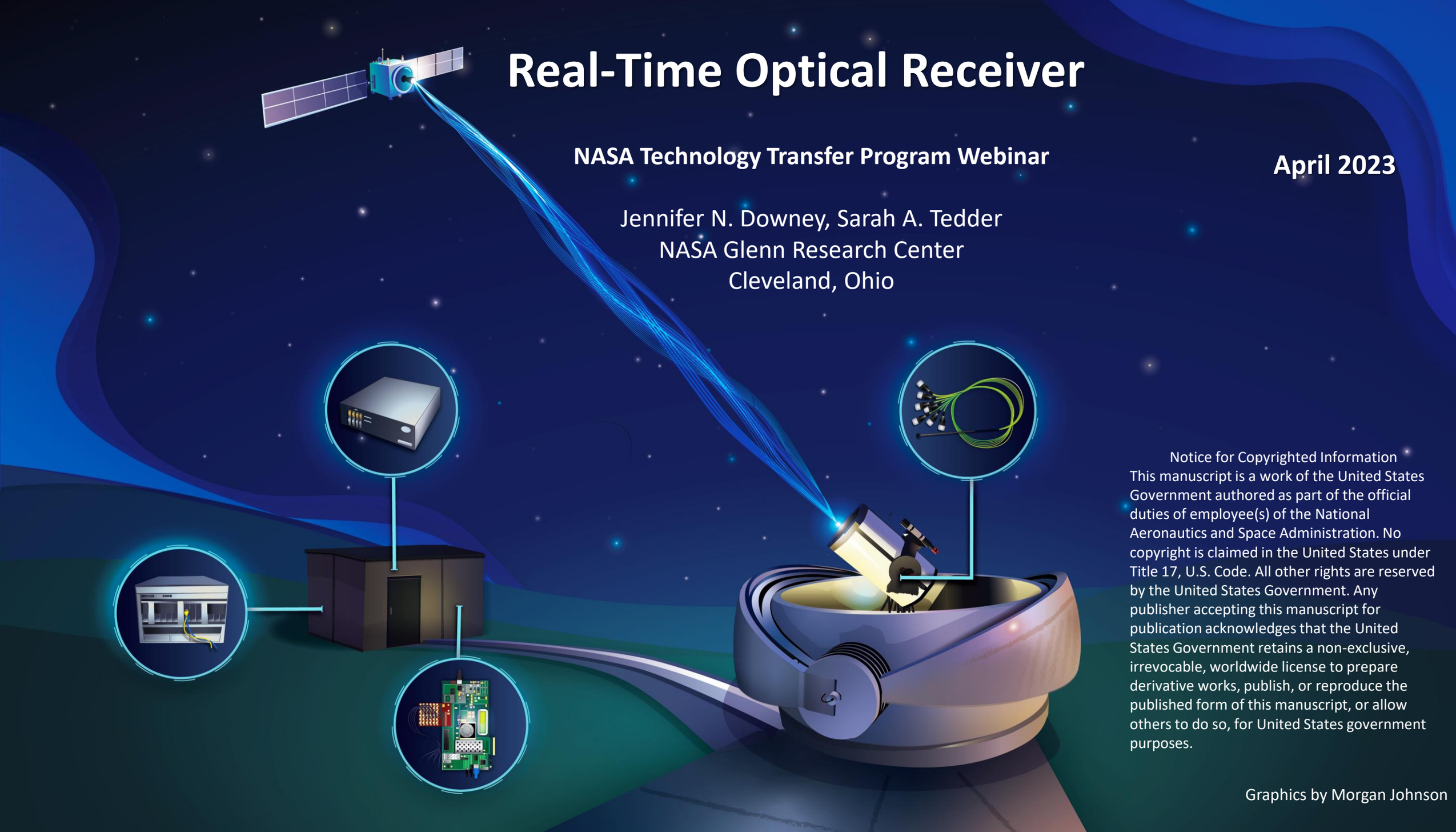
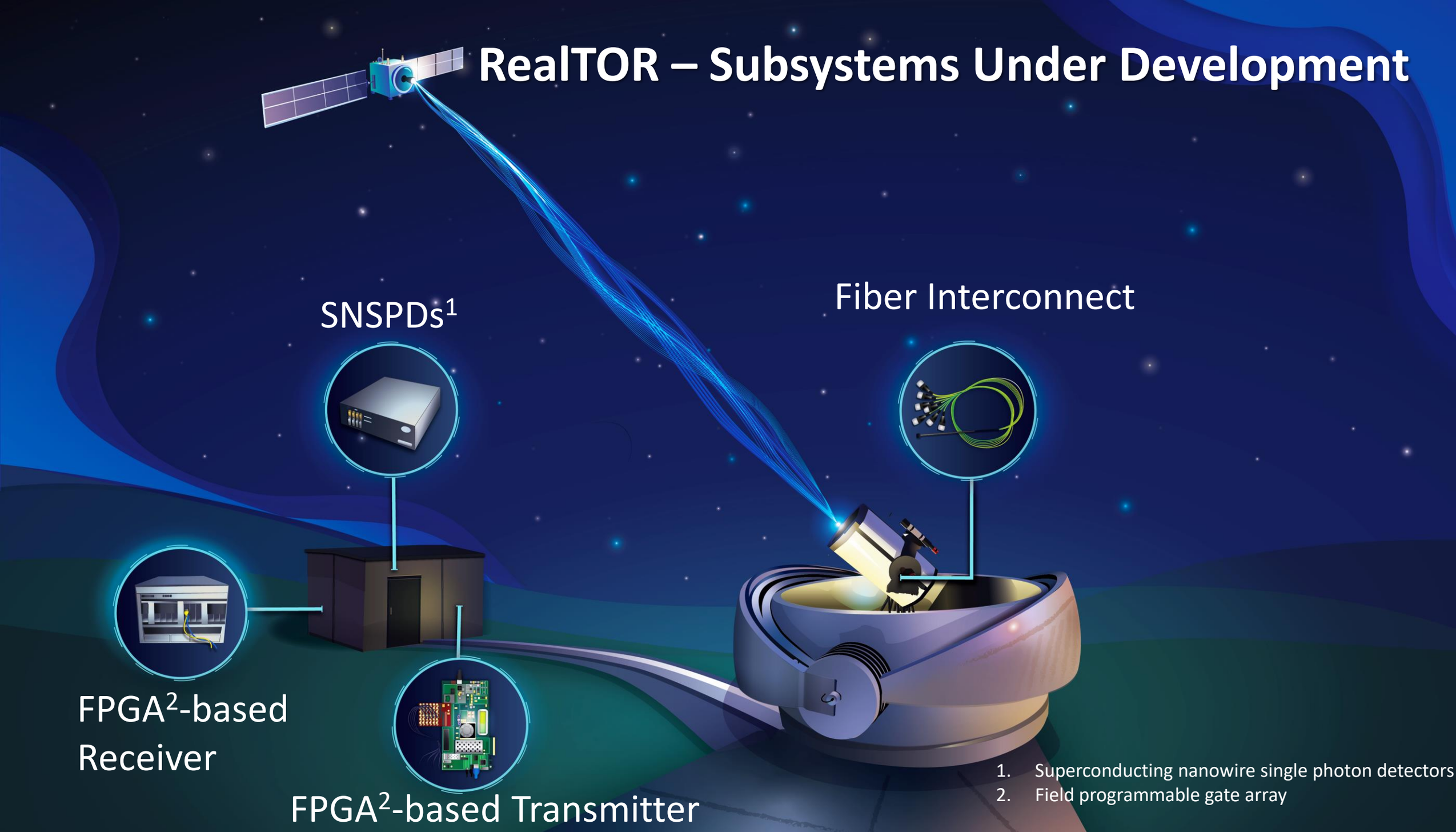


Graphics by Morgan Johnson

Introduction

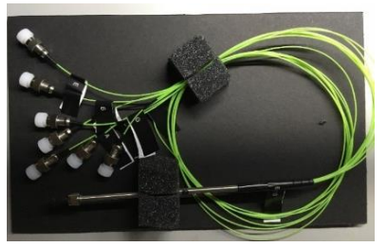
- **NASA is using the CCSDS Optical Communications High Photon Efficiency (HPE) waveform on future missions: Optical Artemis-2 Orion (O2O), Psyche**
  - **PPM: 4, 8, 16, 32, 64, 128, 256**
  - **Slot widths: 512 ns - 125 ps**
  - **Maximum data rate: ~2 Gbps**
- **NASA Glenn is building a photon-counting ground receiver compliant with the CCSDS Optical Communications HPE standard**
  - **PPM: All**
  - **Minimum Slot width: 500 ps**
  - **Maximum data rate: 533 Mbps**
- **Goals:**
  - **Utilize commercial off the shelf (COTS) components**
  - **Demonstrate with O2O at the NASA Goddard Low Cost Optical Terminal (LCOT) ground station**
  - **Transfer technology to commercial company**

RealTOR – Subsystems Under Development



1. Superconducting nanowire single photon detectors
2. Field programmable gate array

Receiver Subsystems Under Development

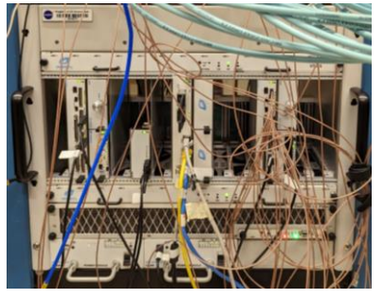


Fiber Interconnect:

- Photonic lantern (one multimode fiber input to 7 FMF outputs) or FMF
- Input fiber core size, number of outputs, and output fiber core size scalable to application
- In house prototyping capability; development partnership with University of Sydney

Single Photon Detector:

- COTS detectors, portable, rack-mounted
- Array of FMF coupled single-pixel detectors sharing one cryostat or single monolithic 16-channel array
- Continuous operation, includes amplifier electronics, 60-80% efficient



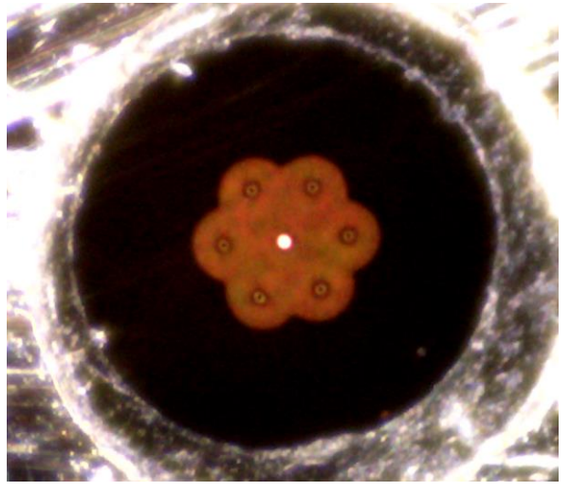
FPGA-based Receiver:

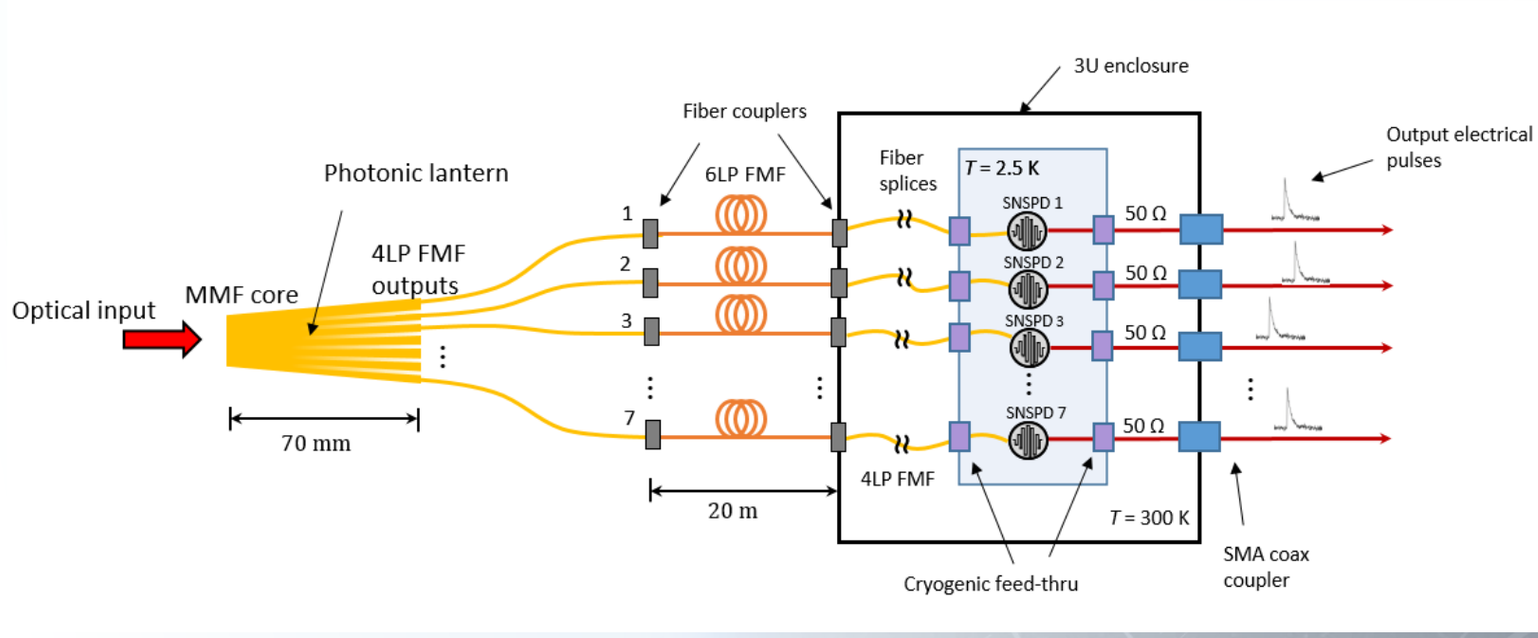
- 1 ADC per detector channel; digital detector channel combining
- Real Time processing; COTS development platform
- Compatible with CCSDS downlink optical waveform (high photon efficiency)
- FPGA VHDL/Verilog receiver code will be released

Photonic Lantern + 7 Single Element Detectors

Photonic Lantern:

- **FMFs:**
  - 20 um graded-index core
  - 4LP, 6-mode
- **MMF input:**
  - 55 um
  - 42 total modes





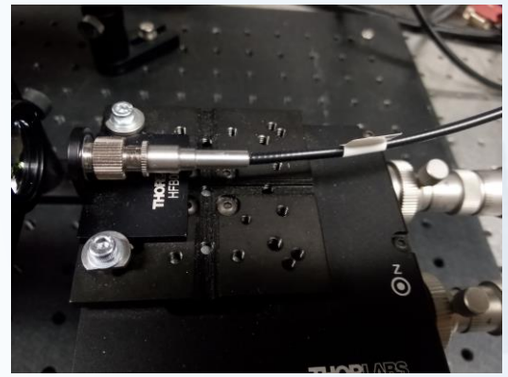
FMF + 16-Channel SNSPD Array

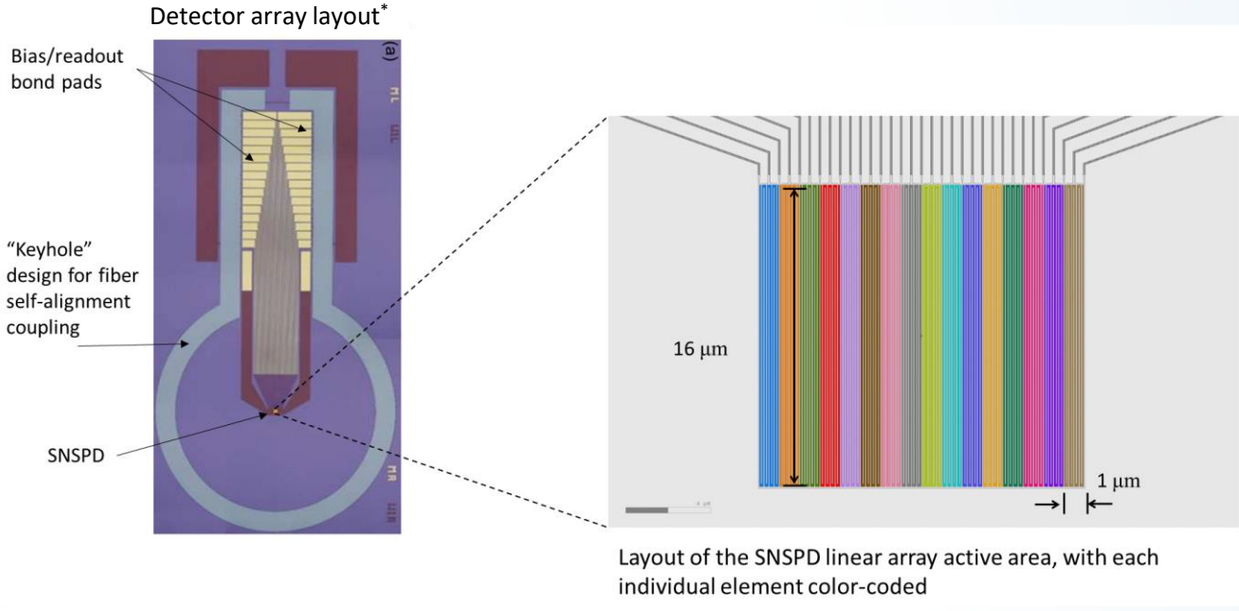
FMF #1 (coupled to SNSPD array):

- 20 um graded-index core
- 4 LP, 6-modes

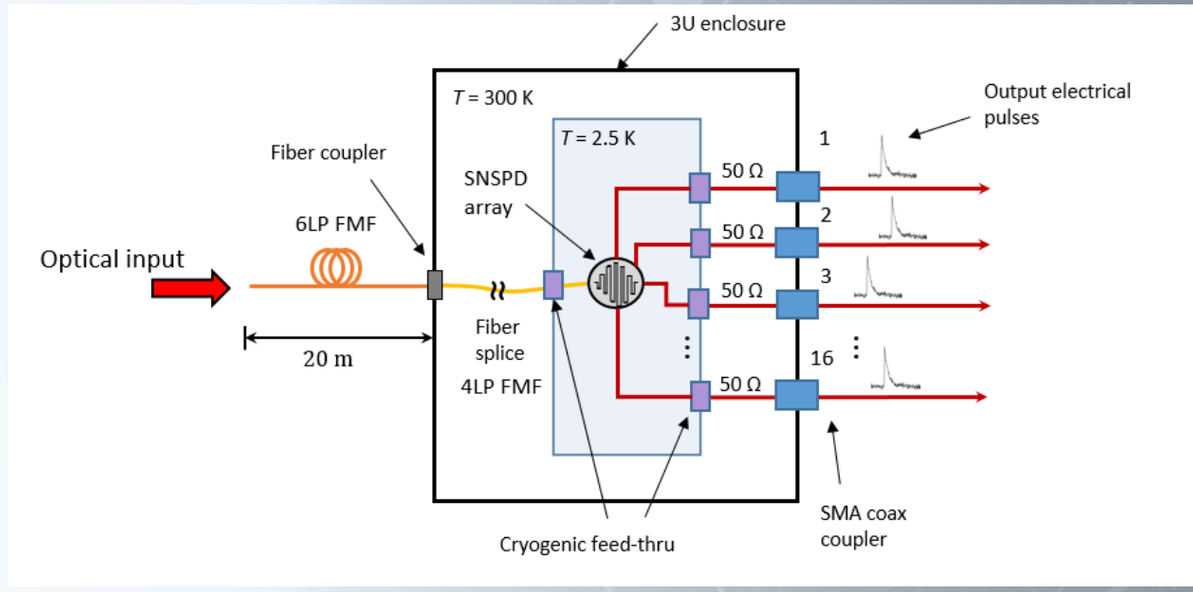
FMF #2 (20 m system input):

- 25 um graded-index core
- 6 LP, 10-modes





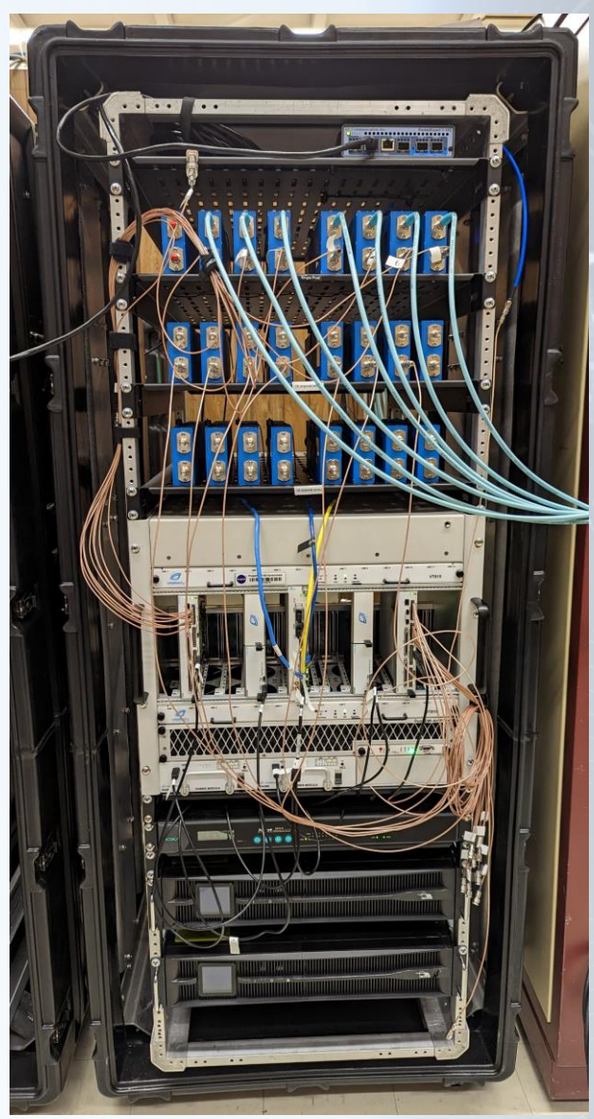
Layout of the SNSPD linear array active area, with each individual element color-coded



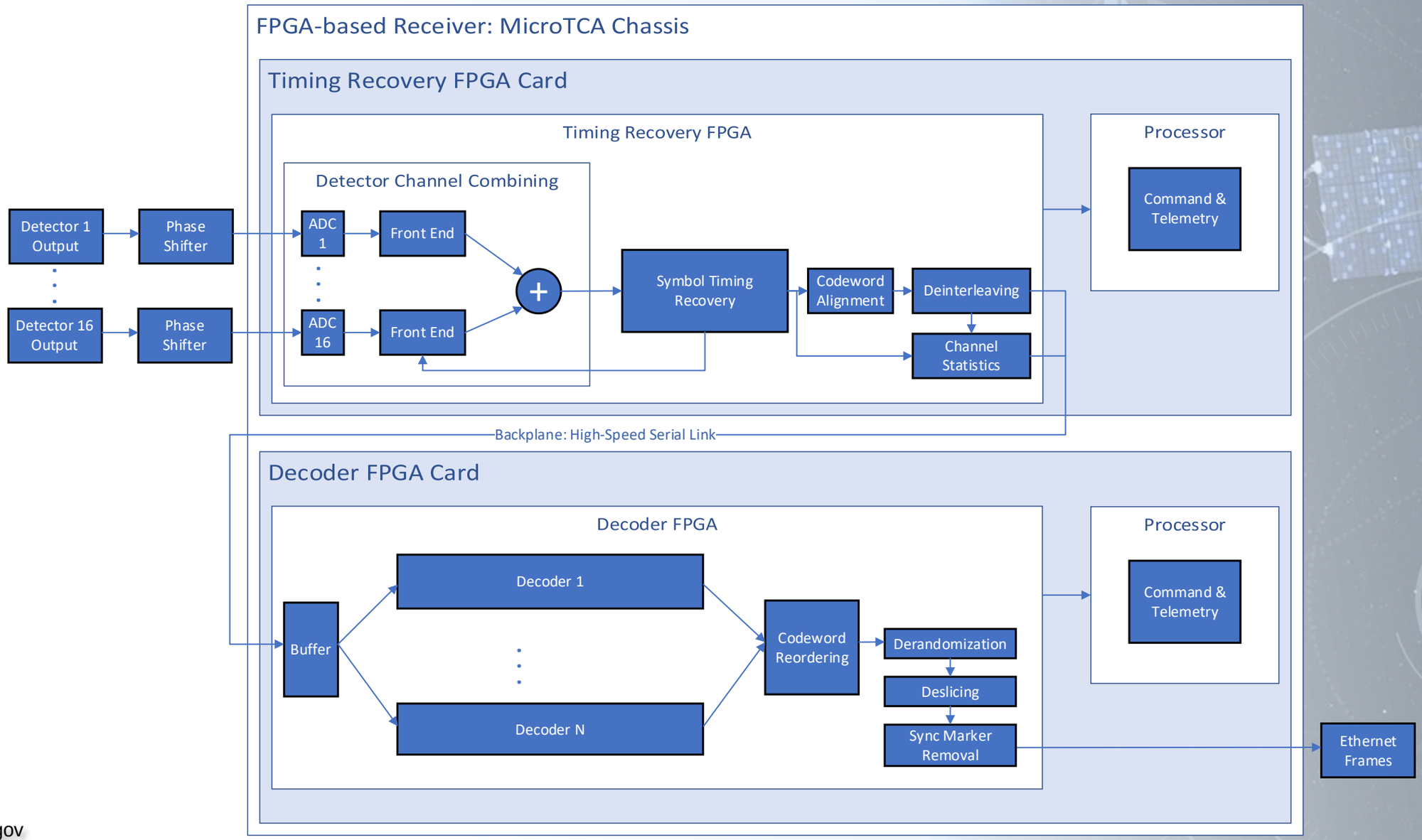
*Rambo, T. M., Conover, A. R., and Miller, A. J., "16-element superconducting nanowire single-photon detector for gigahertz counting at 1550-nm," (2021). https://arxiv.org/abs/2103.14086

FPGA-based Receiver

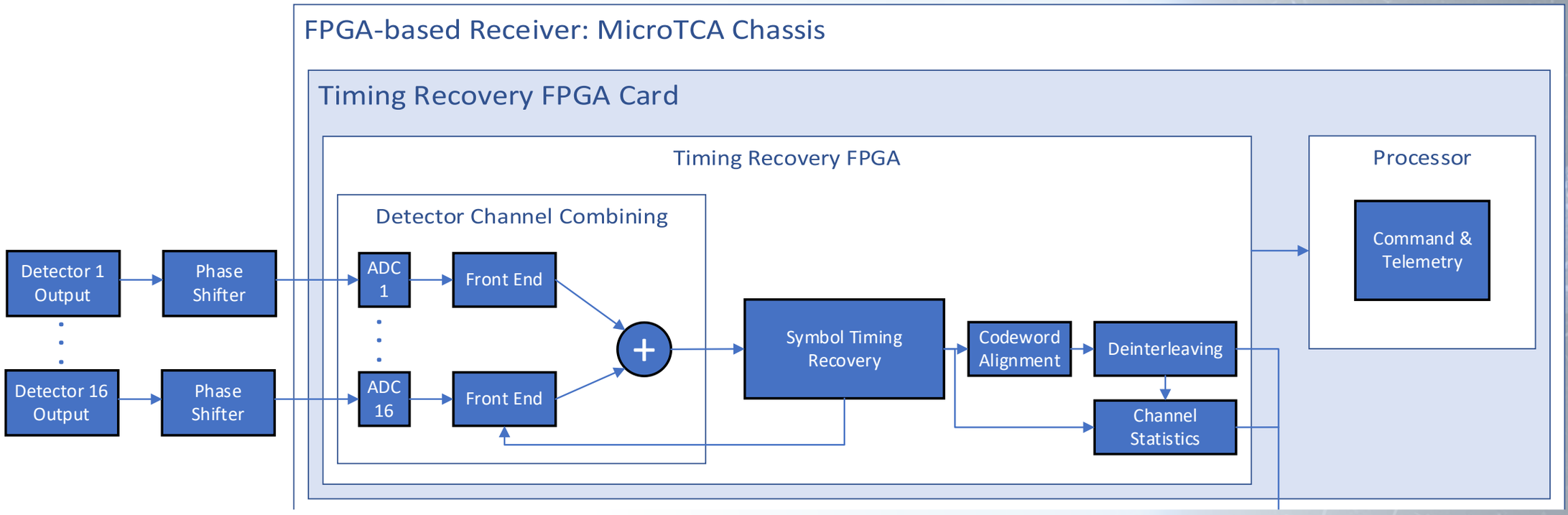
- COTS MicroTCA development platform
- Command/telemetry interface is through HTTP interface built on Space Telecommunications Radio System Architecture



FPGA-based Receiver



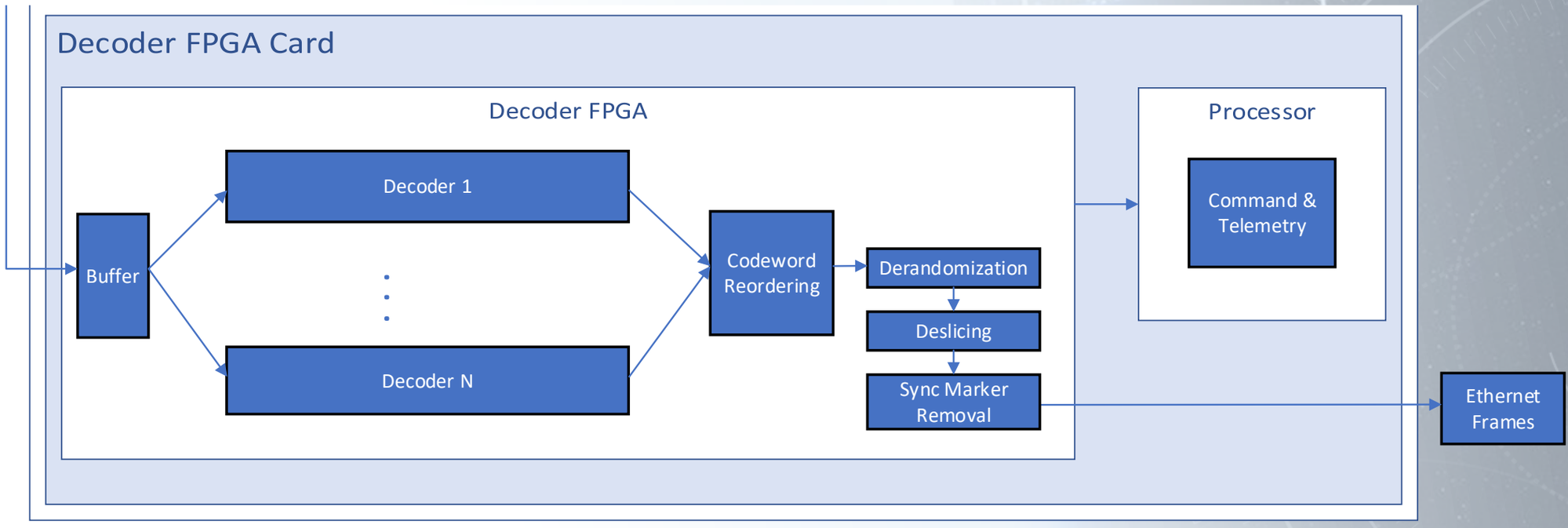
Timing Recovery FPGA



- **Xilinx Radio Frequency System-on-Chip (RFSoC) FPGA with 16 ADCs**
- **Time alignment with mechanical phase shifters**
- **Performs channel combining, photon counting, symbol timing recovery, codeword alignment, convolutional deinterleaving**
- **Calculates channel statistics to send to Decoder FPGA**

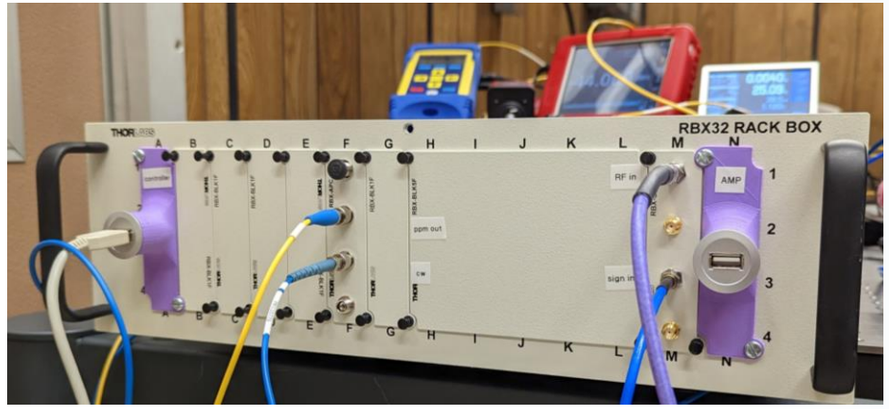
Decoder FPGA

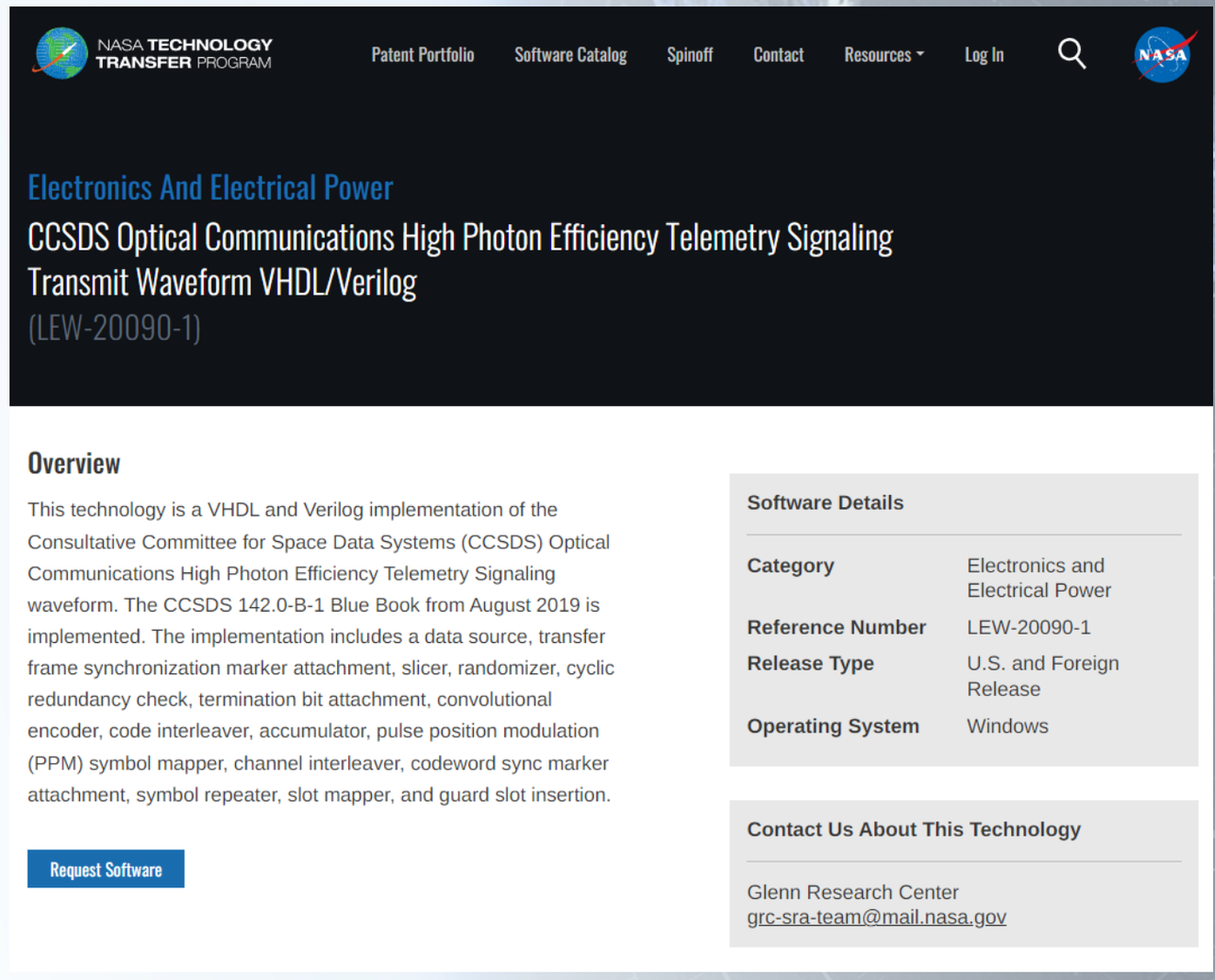
- **Calculates 8-bit slot log-likelihood ratios**
- **Performs BCJR iterative decoding and queuing and reordering for multiple decoder instances**
- **Test mode allows independent characterization of decoder FPGA**



Test Transmitter

- **Transmitter FPGA implements the CCSDS HPE standard**
- **Modulator box performs optical pulse carving with 2 Mach-Zehnder modulators**

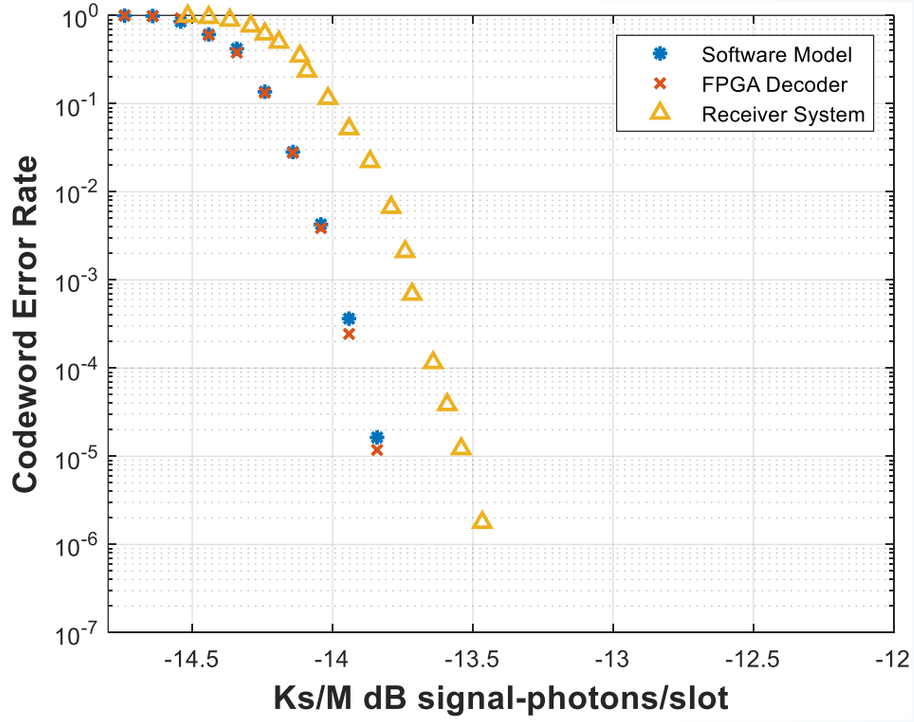




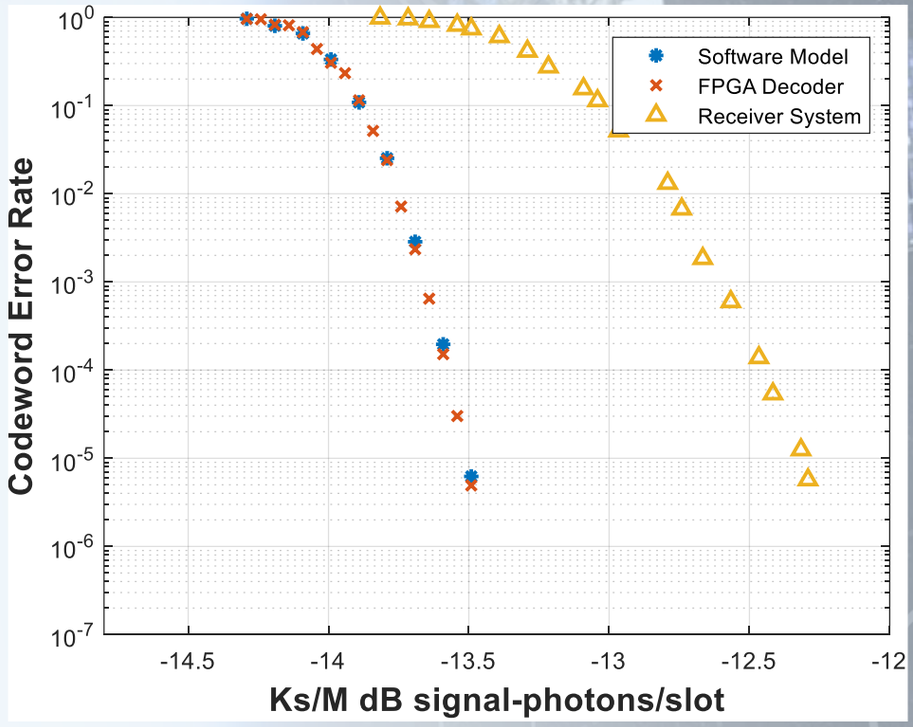
https://software.nasa.gov/software/LEW-20090-1

Codeword Error Rate Curve Results – PPM-16, Code Rate 1/3, 133 Mbps

Photonic Lantern + 7 Single-pixel Detectors



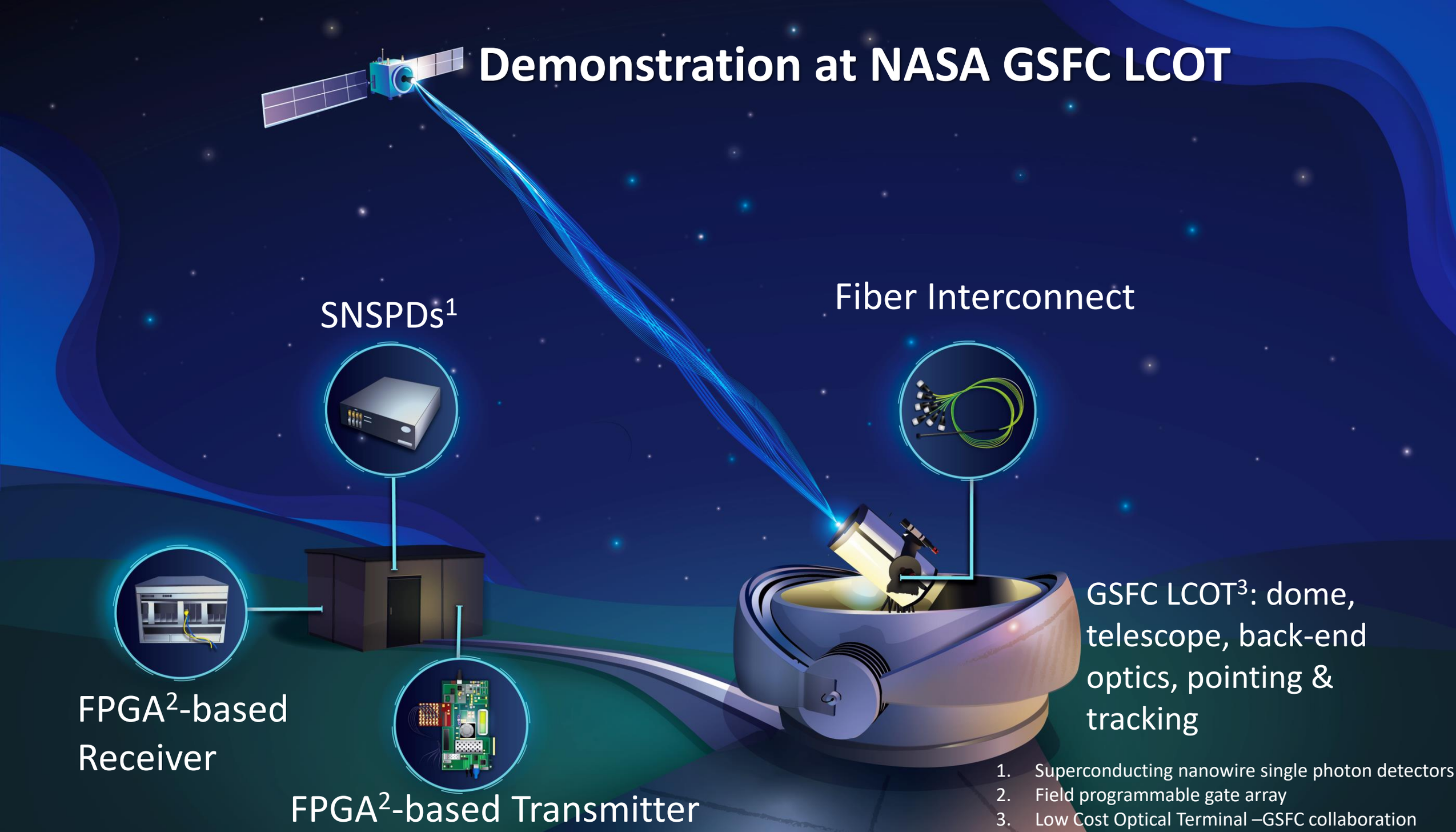
FMF + 16-pixel Detector Array



When operating where the photonic lantern numeric aperture is matched to turbulence conditions, it is expected that both architectures will perform similarly.

Detector Jitter & FPGA Implementation Loss (dB)		Fiber & Detector Loss (dB)		Measured K_b at 10^{-5} CWER (dB photons/slot)		Required Input Power at 10^{-5} CWER (dBm)	
PL	A	PL	A	PL	A	PL	A
0.3	1.2	8.0	3.2	-27.2	-22.0	-72.2	-75.5

Demonstration at NASA GSFC LCOT



1. Superconducting nanowire single photon detectors
2. Field programmable gate array
3. Low Cost Optical Terminal –GSFC collaboration

Conclusion

- **A photon-counting ground receiver has been developed and tested for several CCSDS HPE modes.**
  - **Two fiber/detector architectures were prototyped**
- **When operating in an optical ground station where the photonic lantern numeric aperture is matched to turbulence conditions, it is expected that both architectures will perform similarly.**

Next Steps

NASA Space Act Agreement

- **Reimbursable**
- **Non-reimbursable**

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